Medium-Duty Diesel Combustion (ace136)

Stephen Busch
Sandia National Laboratories

VTO Program Management:
Gurpreet Singh, Michael Weismiller

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Timeline

- December 2017-present: medium-duty diesel research
- Ongoing project with continual guidance from AEC MOU industrial partners and reviewers

Barriers & technical targets

- Lack of quantitative engine combustion databases precludes collaborative model verification and validation
- Inadequate understanding of fuel injection, air motion, and combustion chamber geometry effects on combustion and pollutant formation
- Research priorities for MCCI:
  - Reduced engine-out NOx and particulates
  - Reduced cold-start emissions

Budget

FY18: $750k
FY19: $900k

Partners

Technical advice, regular meetings and teleconferences;
Supplier of new engine

Wisconsin Engine Research Consultants

RANS 3D-CFD simulations;
Model development and evaluation

Relevance

- Improving MCCI combustion system efficiency and emissions behavior will require improved understanding of how spray-wall interactions can promote rapid fuel-air mixing
- Clean catalyst heating operation is critical to enable fuel efficient diesel engines to comply with new CARB regulations (e.g. 0.02 g/bhp-hr NOx)

Objectives for this period

- Test hypotheses about the mechanisms responsible for decreased vortex formation with the stepped-lip piston at near-TDC injection timings
- Develop a modified piston bowl to enhance spray-wall interactions associated with a stepped-lip piston to improve fuel-air mixing
- Develop injection strategies and perform engine performance and emissions testing to understand how post/main quantity and split ratio impact pollutant emissions and heat release behavior
- Begin the design and fabrication of a new, medium-duty diesel research engine

Milestones

FY19

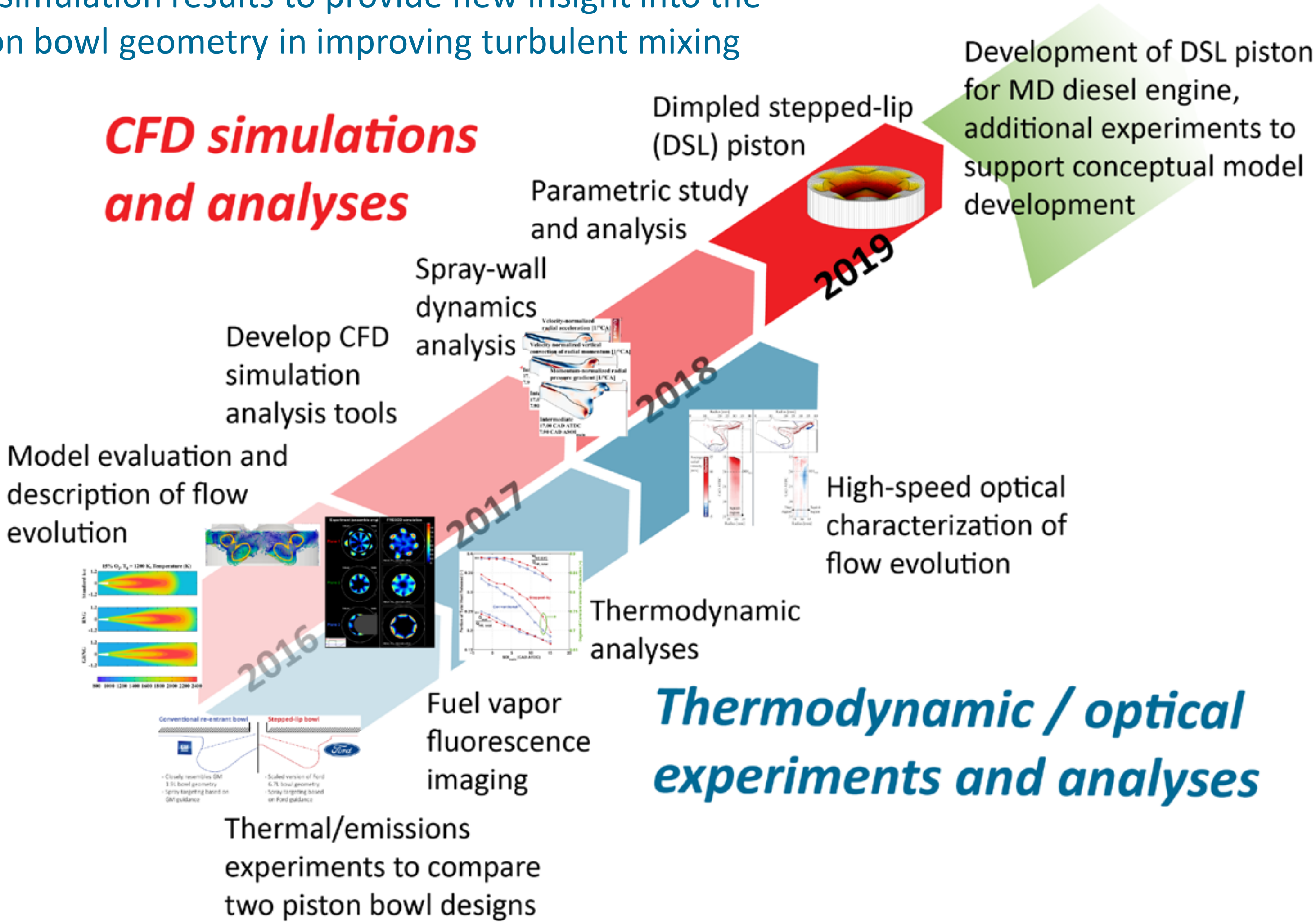
- Q2: Initial performance and emissions measurements with cat heating operation (small-bore)
- Q3: High-speed vis/IR imaging experiments w/ catalyst heating operation (small-bore)
- Q4: First operation of new medium-duty diesel engine (thermal configuration) in lab

FY20

- Q1: Complete shakedown testing of new medium-duty diesel engine
- Q3: Tradeoffs between pollutant emissions and exhaust temperature/heat flux in catalyst heating operation

Approach: piston bowl geometry study

Unique thermodynamic optical experiments and in-depth analyses of simulation results to provide new insight into the role of piston bowl geometry in improving turbulent mixing



Approach: catalyst heating operation study

- Long term goal: conceptual models describing injection, mixture formation, combustion, and pollutant formation mechanisms for multiple injection, catalyst-heating operation

- Address complexity of catalyst heating operating strategies by focusing on simplified subsets; current focuses:
  - Post/main injection quantity/split ratio and timing
  - Fuel boiling range and cetane number

- Develop a family of well-characterized injection schedules with constant pilot, main, and post injection masses

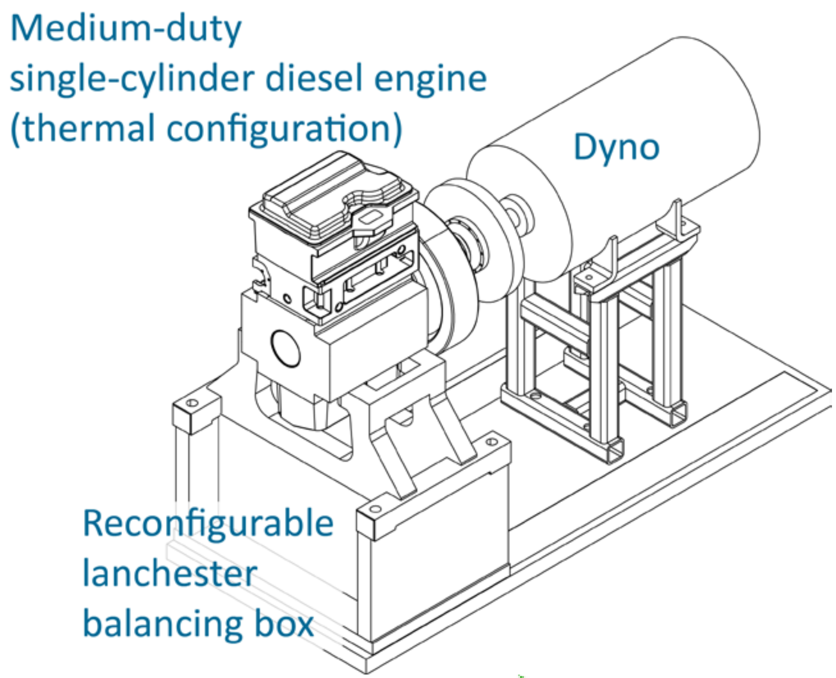
- Perform engine performance and emissions testing using these various injection schedules

- High-speed liquid- and vapor-phase fuel imaging, natural luminosity imaging
  - Provide insight into mixture formation, ignition, and combustion processes

Injected Mass (mg)					Hydraulic start of injection (CAD ATDC)			
Total	Pilot	Main	Post1	Post2	Pilot	Main	Post1	Post2
5	2	3						
7	2	3	<-2->				10,14,18,	
9	2	3	<-4->		-15	TDC	22,26,30	
11	2	3	<-6->					
13	2	3	2	<-6->			10 18	15,20,25,30,35,40 23,28,33,38,43
7	2	5						
9	2	5	<-2->				10,14,18,	
11	2	5	<-4->		-15	TDC	22,26,30	
13	2	5	<-6->					
13	2	5	2	<-4->			10 18	15,20,25,30,35,40 23,28,33,38,43
9	2	7						
11	2	7	<-2->		-15	TDC	10,14,18,	
13	2	7	<-4->				22,26,30	
13	2	7	2	<-2->			10 18	15,20,25,30,35,40 23,28,33,38,43

Progress on new medium-duty research engine

- Conception phase of dual-configuration thermal/optical engine: complete
- Single cylinder short block to be provided by Ford
  - 6.7L Power Stroke® diesel combustion system
- Cylinder heads and liners: fabrication complete
- Dry sump oil cart: fabrication complete, system ready for installation
- Reconfigurable belt-driven balancing box: May 2019 delivery
- Final assembly and shakedown testing: planned completion Fall 2019

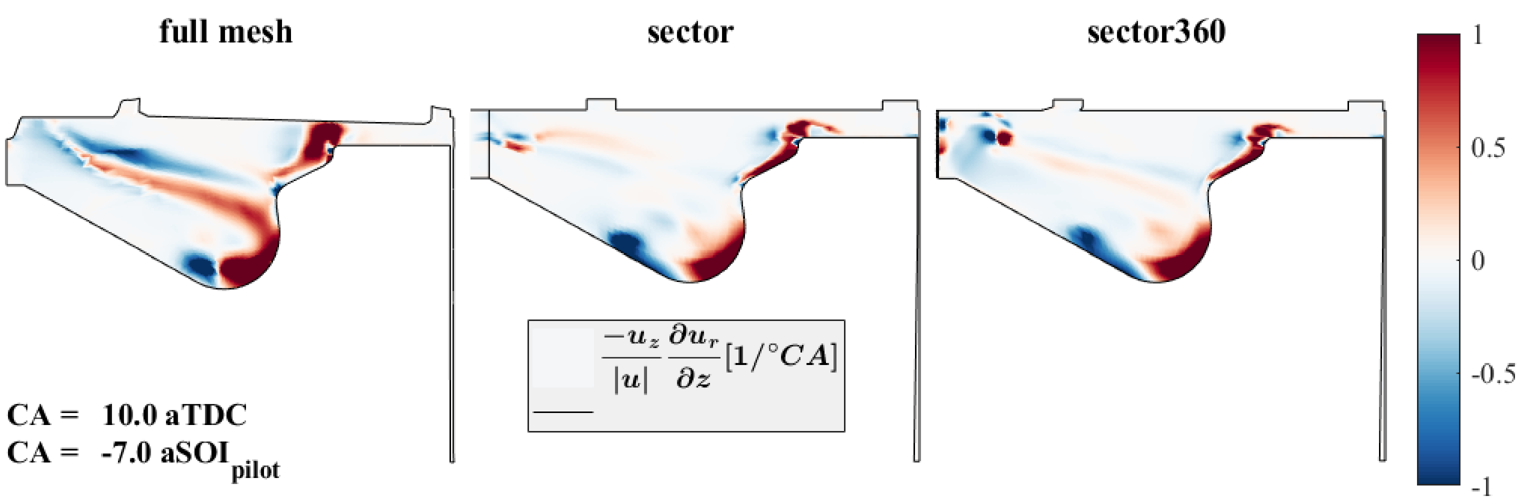


TA: simulation methodology (sector vs. full) impacts prediction of spray-wall interactions

- CFD simulations for the bowl geometry study have been performed on full engine meshes that preclude large parametric studies

- Can a sector mesh capture the spray-wall interactions in manner consistent with experimental predictions?

- Vertical convection of radial momentum is not accurately predicted with a sector mesh or 360° axisymmetric mesh; vortex dynamics in the squish region are only consistent with experimental data with the full mesh.

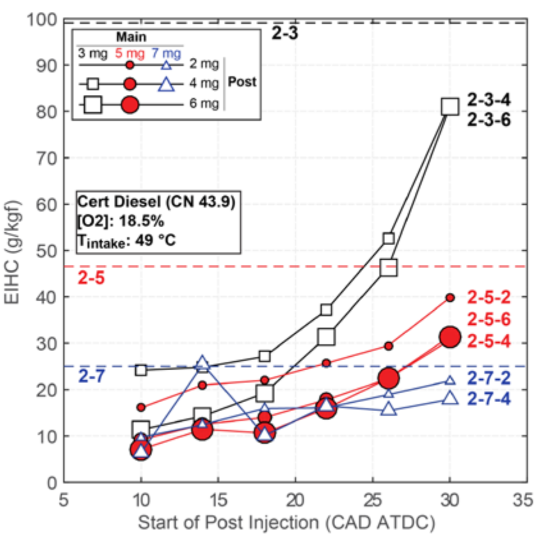


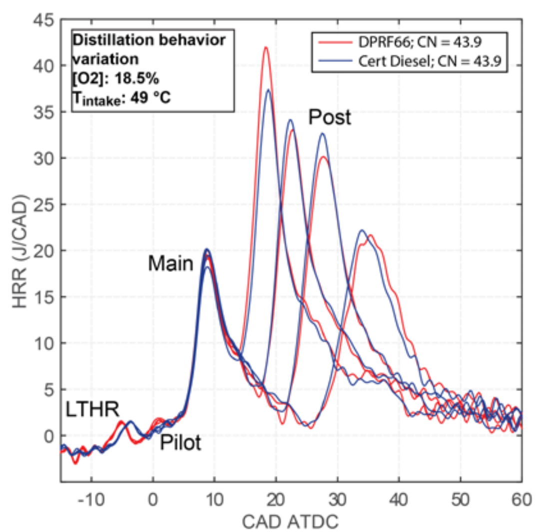
TA: post injections reduce unburned hydrocarbon emissions in catalyst heating operation

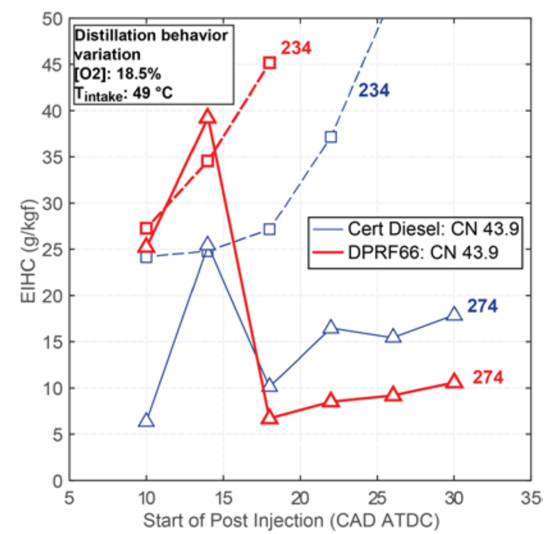
- Preliminary testing for a wide range of injection schedule calibrations
  - Variations of EGR rate, intake temperature, cetane number, and distillation behavior

- Adding the first post injection decreases hydrocarbon emissions, but retarding post injections increases them

- Fuel distillation behavior has a very small impact on post injection heat release, but the full boiling range diesel typically results in significantly lower hydrocarbon emissions







Responses to reviewer comments

- More work should be done to understand the influence of piston speed and load on flow evolution with the stepped-lip piston.
  - We would very much like to better understand these effects, and hope to do so once the new engine geometry is approved for CFD studies.
- Experimental work to better understand spray-wall interactions should continue with the new medium-duty platform as they are critical for mixing-controlled combustion systems.
  - We would welcome the opportunity to continue this work and engage with industry professionals to maintain the value of the research.
- The development and building up of the new medium-duty engine platform may reduce the ability to perform catalyst heating research.
  - This has indeed been a challenge. However, the results from the initial catalyst heating study with the small-bore engine have provided valuable insights. The ongoing analysis of high-speed imaging data will help build understanding of post injection ignition and combustion processes.
- Devoting attention to scaling key measurements/parameters will be helpful when developing engineering-level conceptual models.
  - Parametric studies included in this year's results are a start in this direction. As time and experimental capabilities permit, we are considering experiments designed to inform conceptual models for spray-wall interactions and cat heating operation.

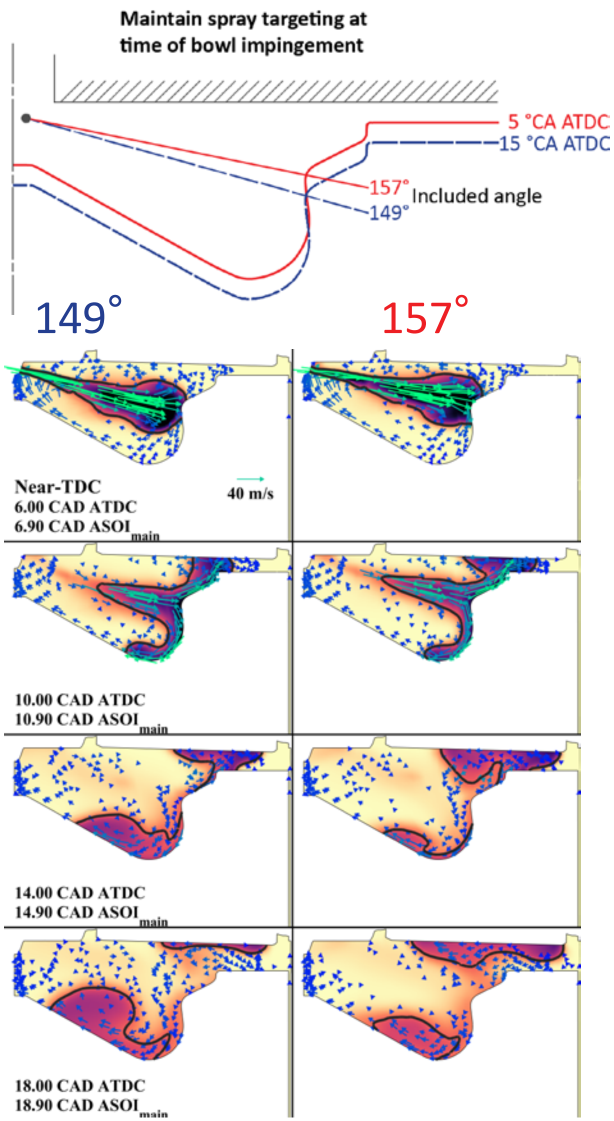
TA: spray targeting alone cannot improve vortex formation with the stepped-lip bowl

- Hypothesis: spray targeting at later injection timings promotes vortex formation in the squish region

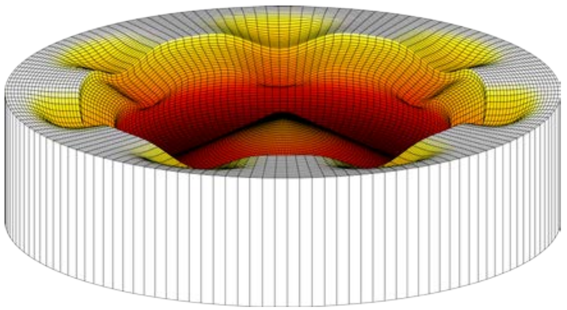
- Test: adjust spreading angle for near-TDC injection so spray targeting matches the later injection case
  - Nozzle holes cannot be translated vertically by this amount due to interference with the head

- Spray targeting affects fuel mass and momentum splitting, but cannot restore the formation of long-lived vortices at near-TDC injection timings

- Space between the piston and head must play a key role in vortex formation in the squish region



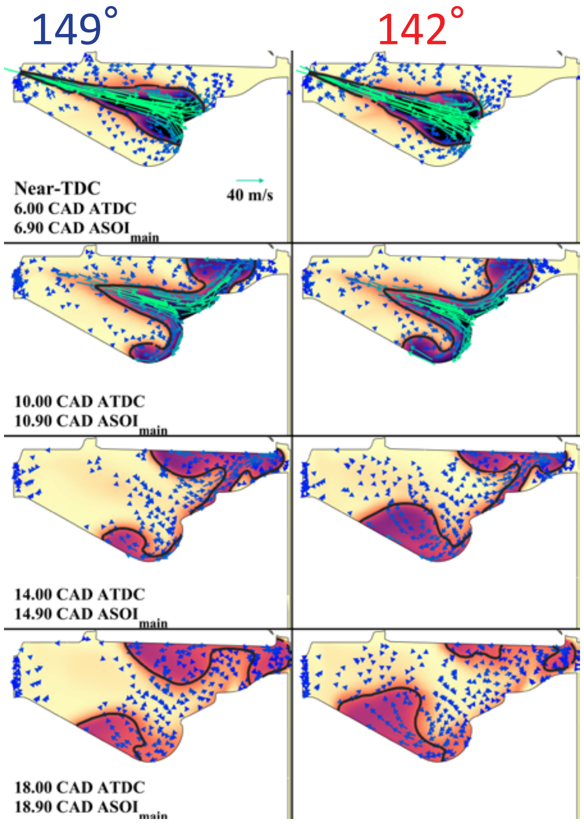
TA: dimpled stepped-lip (DSL) piston promotes vortex formation at near-TDC injection timings



- Hypothesis: more space for each spray in the squish region will enhance vortex formation at near-TDC injection timings

- Test: proposed dimpled stepped-lip (DSL) piston design, CFD simulations with two included angles
  - Intake pressure increased to simulate identical compression ratio

- Providing more space between the piston and cylinder head can promote vortex formation in the squish region at near-TDC injection timings
  - Spray targeting and depth of dimples influence fuel mass/momentum splitting



Remaining challenges / future research

Bowl geometry study

- Is enhancing vortex formation (e.g., with the DSL piston) a means to:
  - Increase mixing-controlled heat release rates?
  - Improve thermal efficiency?
  - Improve the soot-NO_x tradeoff?

- If enhancing vortex formation is important, what geometric aspects of stepped-lip bowl geometry can support this?

- What causes load and speed sensitivities with stepped-lip bowls, and how might this be mitigated?

Catalyst heating operation study

- What is the mechanism by which post injections ignite, and how does it depend on injection timing?

- What is the source of unburned hydrocarbons / formaldehyde emissions? What role does post injection timing/quantity play?